ON CHANGES IN THE CORONA OF JUNE 8, 1918

By John A. Miller

The corona of June 8, 1918, presented several striking features but no other one that occasioned more comment than the series of arches of coronal material that surrounded each of various eruptive prominences; and justly so, because they are unusual phenomena and because they were more numerous, better defined and more conspicuous than those occurring in any other of the recent coronas.[1]

These arches are bright coronal streams about as broad as the average polar ray. The stream issues from the margin of the Sun; and its course in the beginning is sensibly radial, but at a slight distance from the Sun the stream begins to curve toward the prominence, finally meeting immediately above it another similar and similarly placed streamer which comes up from the opposite side of the prominence. These two streamers form an ogival arch strongly resembling a Gothic arch. This bright arch is usually enveloped by another larger one similar in shape and separated from it by a dark space. This one in turn is enveloped by a third and in some instances the third one by a fourth. The arches extending highest seem more ogival (more pointed) than those which they envelop and in some instances the arch nearest the prominence seems to be a continuous stream which issues from the Sun on one side of the prominence, passes over it to the Sun on the opposite side of the prominence. Even in these cases the stream seems thinner and less bright immediately above the prominence than at the bases, and in general the arches are brighter near the edge of the Sun than at even a small distance from it.

It seemed possible that changes in this or other coronal structure might be detected by comparing plates made at two stations separated as far as possible in longitude. The present paper is concerned with a study that we made for this purpose.

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[1] See, however, a discussion by Perrine, *Publ. A. S. P.*, **13**, 196, 1901

Three sets of plates were used in the study.

1. Director Campbell of Lick Observatory most generously put at my disposal a glass positive of a photograph made by the Crocker Eclipse Expedition from the Lick Observatory located at Goldendale, Washington (Long. $8^h3^m21^s.5$. Lat. $45°48'.9$.). The Lick plate was made with a camera whose focal length is approximately 40 feet. Totality at Goldendale lasted for about one minute and fifty-seven seconds. The plate loaned me by Director Campbell was exposed from one minute and fifty seconds to one minute and fifty-two seconds after the beginning of totality.

2. We also had a glass positive, loaned me by Director Slipher of Lowell Observatory, from a photograph made by the Lowell Observatory Eclipse Expedition which was located at Syracuse, Kansas (Long. $6^h46^m52^s$. Lat. $38°5'.3$.). This plate was made with a camera of 38.7 feet focal length and was exposed from $\frac{1}{2}$ to 4th second of totality.

3. Glass positives made from negatives made by the Eclipse Expedition from Sproul Observatory. The Sproul Station was located at Brandon, Colorado (Long. $6^h49^m49^s$. Lat. $38°27'36''$). Brandon is about seventy-five miles from Syracuse and west of it. The Sproul plates were made with a camera of focal length sixty-two and a half feet. Two Sproul negatives were used. One was exposed for two seconds at the beginning of totality and the other for three seconds at the end of totality. For reasons pointed out later a series of five positives which varied considerably in photographic density were made from the last named negative.

The time of mid-totality at Goldendale was roughly twenty-six minutes earlier than that at Brandon.

Miss Margaret E. Powell, a graduate student at Swarthmore College, and I made a study of these plates. We hoped, in the beginning, to be able to identify nuclei or other distinctive features on the various plates, and to establish change of structure, or lack of it, by measuring their positions on the plate. The structure, however, was too non-committal to draw conclusions in this way. We finally decided to confine our attention to the arches, and Miss Powell measured three of them in the following manner. She found geometrically the center of the Moon's image. Having computed the displacement of the center of the Sun relative to that of the Moon for each plate, the position of the center of the Sun was plotted on the plates. A point, which could be certainly identified

on each plate was selected. Choosing a line thru this point and the center of the Sun as initial line, and the center of the Sun as the origin, any point could be located by its polar coördinates, ρ, θ. The polar coördinates of a series of points lying along the middle of the stream forming an arch were measured on the Lick plate. The same series of vectorial angles were set off on the Sproul plates and the corresponding radii vectores measured. The Lowell plate was treated in the same way.

Since the vectorial angles are the same it is evident that if the corresponding radii vectores are the same the arch is not sensibly changed, but that if they are different (assuming the measures are exact) either the shape or the position of the arch has changed in the twenty-six minutes, which elapsed between the exposures.

We chose for measurement three arches. The first is an arch around the Pyramid Prominence which is about $27°$ north of the east extremity of the Sun's equatorial diameter. Toward the pole side of this prominence there are four well defined arches; the second of these arches counting from the prominence, was measured.

The second arch measured was around the Southeastern Prominence which is about $88°$ south of the east end of the Sun's equatorial diameter. There are four well-defined arches on the equator side of the prominence, the inner one of which was measured.

The third is around the Skeleton Prominence which is $8°$ south of the west end of the Sun's equatorial diameter. This prominence has four distinct arches on the equator side, the fourth of which, counting outward, was measured. The arches on the pole side were much less distinct, due, we supposed, to the presence of another prominence beyond the edge of the Sun.

It will be noted that these prominences are well distributed around the circumference of the Sun, and that an error in plotting either the center of the Sun or of the Moon will affect the measures of different arches in different ways. All linear distances on the Lick plate are reduced mathematically to the scale of the Sproul plate by multiplying the quantity measured (on the Sproul plate) by $1.004 \times \dfrac{D_3}{D_1}$, where D_3 and D_1, are the linear diameters of the Moon measured respectively on the Sproul and the Lick plates. The factor 1.004 is computed from the hour angle, the zenith distance of the Moon and its distance from the center of the Earth at the time of totality at the two stations. For example, any meas-

ured radius vector measured on the Lick plate is reduced to the scale of the Sproul plate by multiplying it by $1.004 \times \dfrac{D_3}{D_1}$. In what follows θ denotes the vectorial angles; ρ_1 and ρ_2 are the measures of the radius vectors on the Lick and Lowell plates respectively thus reduced to the scale of the Sproul plate; and ρ_3 the corresponding radius vectors measured on the Sproul plates.

There are three sets of measures. The first set was made with the center of the Moon as origin. The quantity ρ was measured from this point. After the measures indicated that the arches had changed we computed the values of ρ_1 and ρ_3 that would have been obtained had we used the center of the Sun as origin. There were four sets of these measures which we averaged and called Series I. These measures were made on the Lick and Sproul plates only.

About three months later we plotted the actual center of the Sun on each plate and measured the arches on the Lick and Sproul plates again. The vectorial angles are measured from the same point but it was impracticable to set off the same vectorial angles as had been set off before. We called this set Series II.

Two questions arose. The first was whether we should compare plates made with cameras differing so much in focal length. The second was whether or not the difference in the values of the ρ's might not be different because the plates had not had equivalent exposure time.

To answer the first question we measured a Lowell plate. It is evident that because of the proximity of the Sproul and Lowell stations that the values ρ_3-ρ_2 should approximate zero, and that the sum of the differences should be a very small negative quantity; and this is what happens. (See Table I, Series III, and Table II, Series III.) There is a somewhat large discrepancy in the first measure of each of the Lowell and Sproul series because this point was very near the edge of the Sun and the measures were somewhat uncertain.

To answer the second question as nearly as possible we printed with different degrees of density five positives from one of the Sproul plates. We measured two of the arches, on the Lowell plate and on each of these positives of the Sproul plate, using the same set of vectorial angles thruout that was used in Series II.

The values of the Sproul plate given in Series III is the average of the measures made on the series of five positives just referred to.

TABLE I

ARCH ABOVE THE PYRAMID PROMINENCE

Series I				Series II				Series III		
ρ3 (Sproul)	ρ1 (Lick)	ρ3-ρ1 (Sp-Li)	θ	ρ3 (Sproul)	ρ1 (Lick)	ρ3-ρ1 (Sp-Li)	θ	ρ3 (Sproul)	ρ2 (Lowell)	ρ3-ρ2 (Sp-Lo)
4.09	4.10	−0.01	6°06'	4.00	3.90	+0.10	7°28'	3.96	4.02	−0.06
.29	.24	+.05	4 54	.14	.98	.16	6 40	4.12	.17	.05
.38	.28	.10	4 18	.28	4.20	.08	5 33	.26	.27	.01
.44	.32	.12	3 30	.31	.24	.07	5 08	.32	.32	.00
.46	.38	.08	2 36	.48	.36	.12	3 50	.44	.42	+.02
.51	.42	.09	2 12	.53	.45	.08	2 46	.51	.52	−.01
.52	.44	.08	1 36	.56	.49	.07	2 22	.54	.52	+.02

TABLE II

THE ARCH ABOVE THE SOUTHEASTERN PROMINENCE

Series I				Series II				Series III		
ρ3 (Sproul)	ρ1 (Lick)	ρ3-ρ1 (Sp-Li)	θ	ρ3 (Sproul)	ρ1 (Lick)	ρ3-ρ1 (Sp-Li)	θ	ρ3 (Sproul)	ρ2 (Lowell)	ρ3-ρ2 (Sp-Li)
3.87	3.80	+0.07	+1°48'	3.84	3.69	+0.15	+1°45'	3.83	....	......
.94	.82	.12	1 18	.91	.77	.14	1 15	.90	3.87	+0.03
.97	.87	.10	0 48	.97	.86	.11	0 00	.95	.97	−.02
4.00	.93	.07	0 24	4.03	.90	.13	−1 ᷍	4.00	4.02	−.02
.02	.96	.06	−0 18							
.03	.96	.07	0 30							

TABLE III

The Arch Above the Skeleton Prominence

Series I					Series II			
ρ_3 (Sproul)	ρ_1 (Lick)	ρ_3-ρ_1	Θ		ρ_3 (Sproul)	ρ_1 (Lick)	ρ_3-ρ_1	Θ
4.13	4.01	+0.12	20°31′		4.03	3.77	+0.26	18°20′
.20	.10	.10	21 24		.16	.86	.30	20 00
.25	.18	.07	22 30		.22	.98	.24	21 30
.30	.22	.08	24 06		.25	4.11	.14	23 37
.32	.28	.04	24 42		.28	.20	.08	25 10
.36	.31	.05	25 42		.38	.24	.14	26 40
.41	.33	.08	27 00		.38	.28	.10	28 13
.44	.36	.08	28 06					
.47	.41	.06	28 48					
.50	.42	.08	29 48					

TABLE IV

Southeastern Prominence

		1	2	3	4	5	Average
1	−1 25′	4.00	4.00	4.00	4.00	4.00	4.00
2	0	3.94	3.96	3.94	3.97	3.94	3.95
3	1 15′	3.91	3.91	3.84	3.91	3.88	3.90
4	1 45′	3.84	3.84	3.81	3.81	3.84	3.83

They, as well as the Lowell measures, may be compared directly with Series II.

In Table IV I have given the measures of these five positives from the Sproul plate. The positives were of very different density varying from one just as weak as could possibly be made, and yet show the arches, to one as dense as could be made without entirely obliterating the arches. Yet no systematic differences are revealed in the measures. The results for one of the arches is shown in Table IV. The quantity ρ is measured in inches.

In interpreting these results one must not be unmindful of the difficulties of these measures and the consequent uncertainty. I want to consider briefly possible sources of error.

1 The measures themselves: The streamers from their nature are somewhat indefinite, tho the photographs were very good. The measures were very conscientiously made. No one could have been more painstaking than Miss Powell has been. Series I was made three months before Series II and eight months before Series III, so that no prejudice could have been carried into the measures. Any two series are reasonably consistent and the last two remark-

ably so, and in one thing absolutely so—the quantity ρ_3-ρ_1 is always positive. These tables were made up by averaging a series of individual measures. There were 156 individual measures. Eight of these gave negative ρ_3-ρ_1. Moreover, the ρ's measured on the two Sproul plates, one made at the beginning, the other at the end of totality, are remarkably accordant.

2. An error in plotting the center of the Sun will change the values ρ_3-ρ_1. However, if one will make a drawing of the Sun and the three arches that were measured (for location of arches see page 209) he will find that the distribution of the arches is such that an error which decreases any given set of ρ_3-ρ_1, will increase one or both of the remaining two sets. That is, one cannot choose an origin that will make all of these differences disappear. Moreover, the center of the Sun was determined four times on each of the plates and measures of the arches made after each determination.

3. The equivalent exposure times of the various plates differ somewhat. Is it possible to account for the discrepancy in this way? This I have discussed on page 210. In addition we measured the diameter of the Moon on the Sproul plates made from negatives exposed three seconds and two seconds respectively. These differ in effective exposure about the same amount, as the Sproul and Lick plates measured. The diameters of the Moon on these two Sproul plates are the same.

I can think of no other probable source of error. It is my belief that these measures show that these arches have changed in the twenty-six minutes time interval and that they are going outward from the Sun. Assuming the measures are correct, this would mean that these arches are receding from the Sun at the rate of about ten miles per second.

There are many other places in the corona that one feels reasonably certain have changed but they are either too indefinite to measure or one feels that they might be due to some photographic defect. It is not unusual to find streamers issuing from small projections on the prominences. For example, from each of three tips of the Southeastern Prominence there issues a stream and each stream assumes approximately the form of the arch above them.

There was an exposure of forty-five seconds made with this same lens (sixty-two and a half feet focal length) at the Sproul Station. Miss Smedley, an assistant at the Observatory, and myself con-

cluded independently from an examination of this photograph that
no one could guess from the shape of the long streamers of the corona
that there was a violently disturbed region in the Sun immediately
below them. As a matter of fact, the long streamers may not be im-
mediately above the prominences tho they appear to be in the
photograph. But no one can tell by an examination of the outer
corona that the Sun's surface was at that time very active.

There was another feature of this corona which I believe is un-
usual. Ordinarily the polar rays seem to be arranged symmetrically
with regard to an axis which differs, but not much, from the rotation
axis of the Sun. This difference is a function of the position of the
Earth in its orbit and of other things. Moreover, if one measures
the polar coördinates of the points on a polar ray, measuring the
vectorial angles from the west extremity of the Sun's diameter, he
will generally find for a polar ray west of the axis of symmetry that
the vectorial angle decreases as the radius vector increases, and for
a polar ray east of the axis of symmetry that the vectorial angle
increases as the radius vector increases. That is, that the polar
rays are curved away from the axis of symmetry. In the corona
of 1918 the polar rays likewise curve away from the axis of sym-
metry, but in such a way that whether the ray is east or west of the
axis of symmetry, the vectorial angle decreases as the radius vector
increases. That is, the polar rays east of the axis of symmetry are
curved away from it very much less than those west of it, and it is
easy to show that this is not a projective effect. The appearance of
these streamers suggested that some sort of current had changed
somewhat the direction of all these rays.